# Device for recording and device for reproducing three-dimensional items of image information of an object

This invention relates to a device for recording of three-dimensional image data of an object as claimed in the preamble of claim 1. This invention furthermore relates to a device for reproduction of three-dimensional image data of an object as claimed in the preamble of claim 14. Furthermore, this invention relates to a process for recording and reproduction of three-dimensional image data of an object. In addition, this invention relates to a microscope, a video device and a photo device for recording and reproduction of three-dimensional image data of an object.

A device for recording and a device for reproduction of three-dimensional image data of an object, a process for recording and reproduction of three-dimensional image data and a photo means for recording and reproduction of three-dimensional image data are known from Lippmann G., J. de phys. theor. et appl., 1908, vol. 7, pp. 821 - 825. The photo device described in this literature citation is also known as an integral photography device. In the device described therein, the light emerging from an object is imaged by a lens array with a plurality of lens elements onto a photographic plate. The lens elements are for example arranged comparatively tightly next to one another on a square surface so that the light emerging from the object passes through each of the lens elements at a somewhat different angle. Somewhat different images of the object are formed on the photographic plate behind each of the lens elements. The photographic plate can be developed so that a photo can be made. In front of this photo according to the aforementioned prior art exactly the same array of lens elements can be positioned such that the individual images of the

object can be merged again into an overall picture of the object for the viewer by the array of lens elements. This picture is a three-dimensional picture.

A device for recording and a device for reproduction of three-dimensional image data, a process for recording and reproduction of three-dimensional image data and a photo means for recording and reproduction of three-dimensional image data of the initially mentioned type are known from US patent US 2,174,003, in which arrays of cylinder lenses, which arrays are crossed to one another, form lens elements for the imaging of the object onto recording means. Integral photographs can also be produced using these lens elements. The disadvantage in this device is on the one hand the comparatively poor imaging of the partial beams which have passed through the edge areas of the lens means and on the other hand the low contrast between the partial beams of light which have passed through the different lens elements.

US patents US 3,852,524 and US 3,878,329 further develop the original devices of Lippmann such that photomultipliers are used as the recording means and cathode ray tubes are used as the reproduction means. In international patent application WO 94/09390 CCD chips are proposed as the recording means and liquid crystal displays are proposed as the reproduction means.

In European patent application EP 0 520 179 A1 it is suggested that three-dimensional image data be digitally prepared, especially improved by interpolation with respect to resolution. Then these image data are printed out such that they can be viewed using the corresponding lens means as a three-dimensional picture.

The object of this invention is to devise a device for recording and a device for reproduction of image data of the initially mentioned type, which are built to be more efficient. Furthermore, a

process for recording and reproduction of image data of the initially mentioned type which can be more efficiently carried out will be given. Furthermore, a microscope, a video device and a photo device for recording and reproduction of image data of the initially mentioned type which are built to be efficient will be devised.

This is accomplished as claimed in the invention with respect to the device for recording of three-dimensional image data by the features of claims 1 and 2, with respect to the device for reproduction of three-dimensional image data by the features of claim 14, with respect to a process for recording and reproduction of three-dimensional image data by the features of claim 20, with respect to the microscope for recording and reproduction of three-dimensional image data by the features of claim 22, with respect to the video device for recording and reproduction of three-dimensional image data by the features of claim 23, and with respect to the photo device for recording and reproduction of three-dimensional image data by the features of claim 24.

As claimed in claim 1, it is provided that the curvature of the cylinder lenses is made greater or lesser in the edge areas of the lens means than in the middle area of the lens means. Especially with greater execution of the curvature of the cylinder lenses in the edge areas the partial beams which are incident at a comparatively large angle in the edge area and which proceed from the object which is to be recorded can be imaged more easily and completely onto the recording means.

As claimed in claim 2, it is provided that between the individual cylinder lenses grooves are formed which extend parallel to the cylinder axes of the cylinder lenses. These grooves can increase the contrast between the light which has passed through different lens elements.

It is possible for the cylinder lenses to have a spherical and/or an aspherical curvature. In particular imaging errors can be avoided by cylinder lenses with at least partially aspherical

curvature.

It can be provided that the lens means have a first array of cylinder lenses and a second array of cylinder lenses, the cylinder lenses of the first array being aligned essentially perpendicular to the cylinder lenses of the second array. These arrays of cylinder lenses which are crossed to one another can be easily produced on the one hand and on the other can be used with great effectiveness as arrays of imaging elements.

Here it is possible for the first array of cylinder lenses to be made on one entry surface of lens means which can be turned toward the object and for the second array of cylinder lenses to be made an one exit surface of the lens means which can be turned away from the object. For example, here the entry surface and the exit surface can be made on a glass substrate or the like. But it is also possible for two or more glass substrates or the like to be arranged behind one another, on the entry surface of one of the glass substrates or the like there being an array of cylinder lenses and on the exit surface of another of the glass substrates or the like an array of cylinder lenses which is crossed to the first is made.

Here it is possible for each of the lens elements to be formed by one cylinder lens on the entry surface and for one cylinder lens to be formed on the exit surface. This configuration makes it possible to comparatively easily build the lens elements.

It can be provided that the distance between the recording means and the lens means corresponds roughly to the focal length of the lens elements. In this way the imaging is good for an object which is comparatively far away from the lens means.

In particular, the distance between the recording means and lens means can be variable. Depending on the distance of the object from the lens means, by changing the distance between the

lens means and the recording means it is possible to influence the imaging of the object on the recording means.

For example, the recording means can comprise one part of a printing device on which changes can be achieved by incident image data such that controlled toner application is enabled according to the image data. Here for example it is possible for a printing roller or the like to be selectively changed by the light which has passed through the lens means by the image data such that a printout which is made according to the image data can be produced.

According to one alternative embodiment of the recording means, it can be provided that they comprise at least one sensor element which can be read out digitally and/or electronically, especially at least one CCD chip or an array of CCD chips. By one such CCD which is used as a sensor element the image data of the light which has passed through the imaging means can be easily recorded and output or further processed. Here it can be provided that at least one CCD chip or each of the CCD chips can record the light which has been imaged by the imaging element or the light which has been imaged by a group of imaging elements. For example, in a CCD chip per imaging element the light which has passed through this imaging element could be recorded with a comparatively large number of pixels and thus with high resolution. But it is also quite possible to provide larger CCD chips which record the light which has passed through several imaging elements. In the extreme case it can even be imagined that there is a single large CCD chip which records all the light which has passed through the imaging means.

Advantageously the recording means can record the light which has been imaged by one of the lens elements separately from the light which is imaged by the other of the lens elements. In this way the image data which correspond to the light which has passed through one of the lens

elements can be recorded and processed separately from the image data which correspond to the light which has passed through the other of the lens elements.

It is possible for the device to comprise read-out means and/or processing means which can process and/or read out the image data of the object which has been recorded by the recording means.

It is furthermore possible for the three-dimensional image data to be data about static images for example in the form of photo data or to be image data about moving images for example in the form of video data.

As claimed in claim 14, it is provided that the device as claimed in the invention for reproduction of three-dimensional image data of an object is characterized in that the reproduction means can reproduce image data which have been recorded with a device as claimed in the invention for recording of three-dimensional image data. Moreover, with the device as claimed in the invention for reproduction of three-dimensional image data the aforementioned three-dimensional photos or the aforementioned three-dimensional videos can be reproduced.

In particular, in the device as claimed in the invention for reproduction of image data the lens means can be made like the lens means of the device for recording of image data as claimed in this invention. Thus, for example, also the lens means used within the framework of recording of image data can be located in front of the reproduction means in order to enable three-dimensional reproduction of the recorded image data. If thus the lens means are made as two cylinder lens arrays which are crossed to one another, these arrays of crossed cylinder lenses can also be located in front of the reproduction means in order to enable viewing of a three-dimensional photo or three-dimensional video.

Furthermore, it is possible for the lens means to correspond to the lens means of the device for recording of image data as claimed in the invention, but to be made smaller or larger compared to it. In this way it is possible to also assign correspondingly enlarged lens means to enlarging reproduction means so that by comparatively simple measures a for example enlarged three-dimensional image of the object can be produced.

The reproduction means as claimed in the invention can be made as a passive reproduction means, especially as a printout or the like. A printout certainly constitutes a very easily implemented form of the reproduction means. In particular a printout can also be easily scaled, for example doubled or tripled in its size. Only accordingly enlarged or reduced imaging means need be selected according to the size of the printout.

According to another preferred embodiment of this invention, the reproduction means are made as active reproduction means, especially as a screen or display in the form of a cathode ray screen or liquid crystal display or as an optical image output device, for example as a beamer or laser television or the like. It is thus for example possible to position lens means which are made as an array of crossed cylinder lenses in front of a liquid crystal display so that the image data of the recorded object can be output three-dimensionally by such an arrangement.

As claimed in the invention, the device for reproduction can likewise be made such that the image data are data about static images, for example in the form of photo data, or data about moving images, for example in the form of video data. Therefore it is also especially possible to provide a liquid crystal display with a corresponding lens means so that the viewer can watch three-dimensional videos.

As claimed in claim 20 the process as claimed in the invention calls for three-dimensional

image data of an object to be recorded by means of a device as claimed in the invention for recording of three-dimensional image data and for the recorded three-dimensional image data to be reproduced by means of the device as claimed in the invention for reproduction of three-dimensional image data.

Advantageously, after recording and before reproduction of image data, they can be processed, especially digitally processed. The prior art discloses the problem that photos prepared with integral photography often show two three-dimensional images, specifically one in front of and one behind the reproduction means. This can be prevented as claimed in the invention by digital image processing so that the viewer for example perceives only one image behind the reproduction means, for example behind the surface of the liquid crystal display.

The microscope as claimed in the invention is characterized as claimed in claim 22 in that the image data can be recorded with a device as claimed in the invention for recording of three-dimensional image data and can be reproduced with a device as claimed in the invention for reproduction of three-dimensional image data. Observation of biological objects three-dimensionally with the microscope as claimed in the invention is an especially good idea here. Here for example the viewer could view three-dimensionally the object to be studied on reproduction means which are made as a liquid crystal display and on which the corresponding lens means are located. An object which is viewed three-dimensionally in this way can be much more easily manipulated than an object viewed two-dimensionally.

The video device as claimed in the invention is characterized as claimed in claim 23 in that the image data can be recorded with a device as claimed in the invention for recording of three-dimensional image data and can be reproduced with a device as claimed in the invention for

reproduction of three-dimensional image data.

The photo device as claimed in the invention is characterized as claimed in claim 24 in that the image data can be recorded with the device as claimed in the invention for recording of three-dimensional image data and can be reproduced with a device as claimed in the invention for reproduction of three-dimensional image data.

Other features and advantages of this invention are illustrated using the following description of preferred embodiments with reference to the attached figures.

Figure 1a shows a side view of the device as claimed in the invention for recording of image data of an object;

Figure 1b shows a view according to the arrow I b in Figure 1a;

Figure 2 shows a view according to the arrow II in Figure 1a;

Figure 3 shows a view according to the arrow III in Figure 1a;

Figure 4a shows a side view of the device as claimed in the invention for reproduction of image data of an object;

Figure 4b shows a view according to the arrow IV b in Figure 4a;

Figure 5a shows a side view of lens means of the device as claimed in the invention for recording or for reproduction of image data;

Figure 5b shows a side view of the lens means as shown in Figure 5a, turned by 90°;

Figure 6a shows a side view of lens means of another embodiment of a device as claimed in the invention for recording or for reproduction of image data;

Figure 6b shows a side view of the device as shown in Figure 6a, turned by 90°.

In the aforementioned figures, for better orientation, axes of a Cartesian coordinate system

are drawn.

Figure 1 and Figure 1b show an object 1 which is shown schematically as an arrow. The object 1 can be a self-illuminating object or an object which is illuminated by external light sources. Of the light proceeding from the object, Figure 1a and Figure 1b show individual partial beams 2, 3 which proceed from different ends of the object 1.

The device as claimed in the invention for recording of image data of an object comprises lens means 4 and recording means 5 which are used as imaging means. The lens means 4 on their entry surface 6 and also on their exit surface 7, i.e. both on their side facing the object 1 and also on their side facing away from the object, have an array of especially convex cylinder lenses 8, 9. Here the cylinder lenses 8 on the entry surface 6 have one cylinder axis in the X direction and the cylinder lenses 9 on the exit surface 7 have one cylinder axis in the X direction. The cylinder lenses 8, 9 are thus arranged perpendicular to one another and constitute crossed cylinder lenses 8, 9. In this way, by combining the entry surface 6 and the exit surface 7, a plurality of lens elements 10 is formed which are used as imaging elements which each comprise one cylinder lens portion on the entry surface 6 and one cylinder lens portion on the exit surface 7. These lens elements 10 are clearly apparent from the front view of the entry surface as shown in Figure 2.

The lens means 4 can be imaged both in the X and also in the Y direction more extended than shown in Figure 1a, Figure 1b, and Figure 2, especially the lens means 4 can comprise many more lens elements 10 than shown.

Grooves 11 are formed between the cylinder lenses 8 on the entry surface 6. Grooves 12 are formed between the cylinder lenses 9 on the exit surface 7. Partial beams from an object 1 which are incident on these grooves 11, 12 either do not pass in the direction to the recording means 5

through the lens means 4 or are deflected uncontrolled such that they cannot be picked up by the recording means 5 or cannot be selectively picked up. The grooves 11, 12 thus increase the contrast between light which has passed through different lens elements 10.

The cylinder lenses 8, 9 can have a spherical curvature. But as claimed in the invention it is also quite possible for the cylinder lenses 8, 9 to be made as cylinder lens-like lenses with an aspherical curvature. Here for example a parabolic, elliptical, hyperbolic, sinusoidal or polynomial curvature of higher order can be chosen.

As claimed in the invention, it is possible for the cylinder lenses 8, 9 which are located in the edge areas of the entry surface 6 or the exit surface 7 to have a greater or lesser curvature than the cylinder lenses 8, 9 in the central or middle area of the entry surface 6 or the exit surface 7. This can result in that the beams which are passing through the lens elements 10 of the lens means 4, which elements are located farther outside, are selectively deflected more strongly or more weakly. It is furthermore possible for the distance of the recording means 5 from the lens means 4 to be changed in order to thus take into account the distance of the object 1 from the lens means 4. In particular, when the distance of the recording means 5 to the lens means 4 corresponds roughly to the focal length of the individual lens elements 10, more or less good imaging of the object 1 onto the recording means 5 by the lens means 4 can be ensured.

It is possible for the image of the object 1 or the parts of the object 1 which are to be recorded onto the recording means 5 to differ by any of the lens elements 10 from any one of the images of the object 1 by the other lens elements 10, in particular any one of the images being produced by different lens elements 10 at different locations on the recording means 5. Such a measure downstream of any one of the lens elements 10 at the points or areas assigned to them on

the recording means 5 yields a somewhat different image of the object 1 or of the parts of the object 1 which are to be recorded, which image differs especially by the recording angle. In this way generation of a three-dimensional image from many different individual images is enabled.

The recording means 5 can be made for example as an array of CCD chips 13, as is indicated schematically in Figure 3. Here for example it is possible for several lens elements 10, especially for example 20 to 70, especially 48, to be assigned to one CCD chip 13. Alternatively, it is possible to assign more than the aforementioned number of lens elements 10 to one CCD chip 13. For example, all the recording means 5 could also consist of a single large CCD chip. Alternatively it would also be possible to assign each of the lens elements 10 to a CCD chip 13 or even to assign more than one CCD chip 13 to each of the lens elements 10.

But as claimed in the invention it is also quite possible, instead of a CCD chip 13 or an array of CCD chips 13, to provide recording means 5 which are made differently. Here it could be recording means which can detect light and which can store the image data contained in this light and/or can relay them to an evaluation unit. Other possibilities for recording means are parts of a printing device such as for example a printing roller or the like on which the image data which correspond to the object 1 trigger changes such that selective toner application can take place according to the image data.

The device as claimed in the invention for recording of image data can furthermore comprise readout means for reading out data from the recording means. In particular, these readout means can be coupled to processing means. Here a computer can be used into which the image data can be read from the recording means 5 which is made for example as an array of CCD chips 13. These data can accordingly be processed digitally.

The device shown in Figure 4a and Figure 4b for reproduction of image data comprises essentially reproduction means 14 and lens means 15 which are used as the imaging means and which are located between the reproduction means 14 and the schematically shown eye 16 of the viewer. In this way it is ensured that the light emerging from the reproduction means 14 is incident through the lens means 15 on the eye 16 of the viewer. In particular, the lens means 15 can correspond exactly to the lens means 4. But it is also possible for the lens means 15 to be larger or smaller than the lens means 4 by a definable factor, depending on whether the reproduction means 14 reproduce the image data recorded by the recording means 5 with the same size, larger, or smaller. A detailed picture of the lens means 15 according to Figure 2 is omitted here, because especially when the lens means 4 and the lens means 15 are the same size they are also made exactly the same according to one preferred embodiment of this invention.

A printout of the image data can be used as the reproduction means 14, for example. This printout would then have to be suitably illuminated in order to enable the viewer to see the image. Instead of a printout, a display screen, for example a liquid crystal display, could also be used as the reproduction means 14. Under certain circumstances here the lens means 15 could be applied directly to the liquid crystal display.

Furthermore, as claimed in the invention it is possible to use the light exit surfaces of optical image output devices such as for example beamers or laser television or the like as reproduction means 14.

A three-dimensional image of the object 1 is made available to the viewer by the devices as claimed in the invention for recording and reproduction of image data. The object 1 can be a static object from which a three-dimensional photo is produced. But it is also quite possible for the object

1 to be a moving object so that moving images of the object are recorded. In this way the device as claimed in the invention for recording and reproduction of image data can output three-dimensional images.

In particular it is possible, after recording and before reproduction of the image data, to process then digitally such that the viewer sees the object in any case as located behind the lens 15. In the prior art which is known as integral photography there is the problem that under certain circumstances two images are formed, specifically one in front of the lens means and one behind the lens means. This can be avoided by the corresponding digital image processing.

Another application of this invention is in three-dimensional microscopy, where especially a biological object can be observed three-dimensionally and in this way can be better altered. Here a device as claimed in the invention for recording and reproduction of image data could be part of a microscope, the viewer being able to look three-dimensionally at the object which is to be studied for example on a reproduction means which is made as a LCD display on which the corresponding lens means are located. Specifically manipulations with extremely small tools can of course be done much more easily on an object which is viewed three-dimensionally in this way.

Figures 5a and 5b show lens means 17 which on their entry surface have cylinder lenses 18a, 18b and on their exit surface have cylinder lenses 19a, 19b. The cylinder axes of the cylinder lenses 18a, 18b on the entry side are perpendicular to the cylinder axes of the cylinder lenses 19a, 19b on the exit side. Figure 5a and Figure 5b show in particular that the cylinder lenses 18a, 18b in the edge areas of the lens means 17 have a weaker curvature than the cylinder lenses 18b, 19b in the center of the lens means 17.

Figure 6a and Figure 6b show lens means 20 with cylinder lenses 21a, 21b; 22a, 22b which

are aligned perpendicular to one another on the entry and exit surface according to Figure 5a and Figure 5b. In contrast to the embodiment as shown in Figures 5a and 5b, however the cylinder lenses 21a, 22a in the edge areas of the lens means 20 have a greater curvature than the cylinder lenses 21b, 22b in the middle of the lens means 20.

**Reference number list**

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| 1 | object |
| 2, 3 | partial beams of light from the object |
| 4, 17, 20 | lens means |
| 5 | recording means |
| 6 | entry surface |
| 7 | exit surface |
| 8, 9 | cylinder lenses |
| 10 | lens elements |
| 11, 12 | grooves |
| 13 | CCD chip |
| 14 | reproduction means |
| 15 | lens means |
| 16 | eye of the viewer |
| 18a, 18b, 19a, 19b | cylinder lenses |
| 21a, 21b, 22a, 22b | cylinder lenses |